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STRESS CORROSION CRACK GROWTH RATES IN GAS PIPELINES

by

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ABSTRACT

Results obtained after 6 months operation of a full size pipe, which was designed to determine stress corrosion crack growth rates are described. Microbial enumeration and metabolic activity measurements were performed on aqueous samples obtained from under disbonded coatings in six soil-containing environmental cells. After six months of operation a number of cells showed a decreasing redox potential profile with increasing soil depth. Total aerobic heterotrophs and acid producing bacteria were generally highest at the top region of the buried pipe. Initial results indicate that the anaerobic denitrifying and sulfate-reducing bacteria are more numerous in cells which contained an iron sulfide layer. Hydrogenase activity did not correlate with sulfate-reducing bacterial numbers, but did correlate with soil type and physical location around the pipe. Crack growth has yet to be recorded. The experiment is in its seventh month of a 12 month time frame.

Keywords: stress corrosion, crack growth, bacteria, gas pipeline, redox potential, water content

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INTRODUCTION

Stress corrosion cracking (SCC) has been observed recently in many locations on natural gas pipelines operated by TransCanada Pipelines (TCPL) and NOVA Corporation of Alberta. The TCPL lines have experienced several service failures from growing SCC. The field investigations have shown that SCC occurs under disbonded coatings. As these cracks grow they coalesce into longer cracks, and eventually penetrate the pipe wall leading to a leak or rupture.

The principal aim of the present joint research project with NOVA, TCPL, University of Waterloo, and NOVA/Husky Research corporation (NHRC), is the determination of growth rates of intermediate or larger SC cracks under field simulated conditions.

MATERIALS AND METHODS

The research at CANMET is being conducted jointly by MSL and MTL. A linepipe which is housed at MTL, is pressurized by a one year simulated gas pipeline spectrum. The test pipe was excavated from a seventeen year old pipeline experiencing SCC. A total of ten environmental cells, four with aqueous electrolytes simulating solutions found under disbonded coating, and six with soil from pipeline sites where SCC was found have been placed on the pipe. A complete description of the ten cells is given in Table 1. MSL is

responsible for the monitoring of biological and physical parameters in the six soil-containing cells. Artificial cracks monitored by the Direct Current Potential Drop (DCPD) crack growth data acquisition system and colonies of natural SC cracks will be used to assess the role of biological processes in crack growth. Redox potentials(Eh) at depths of 10.2 centimetres (4 inches), 17.8(7), 25.4(10), 41.9(16.5), and 77.5 centimetres(30.5 inches) in each soil-containing cell are being measured with glassy carbon electrodes and a saturated calomel reference electrode. Percent volumetric water content is being measured at the same depths using parallel stainless steel rods and the principles of time domain reflectometry. Different bacterial metabolic communities are being enumerated in electrolyte samples obtained from beneath disbonded coatings with the media listed in Appendix A.

RESULTS AND DISCUSSION

The Eh profiles vary from cell to cell (FIG.1). Measurements recorded February, 1991 indicate that Cell 5 (TCPL soil) demonstrates an expected profile in which the Eh declines with increasing soil depth. Near the surface the potential is approximately 250-300 mV, while at the 77.5 centimetre (30.5 inch) depth it has dropped to -225 mV. Cell 10 (Alberta soil) possessed Eh values higher than expected near the surface but did show a very acceptable profile which declined with soil depth. The profiles of cells 6 and 7 were flat. Cell 8 had a profile that declined with

depth but its values are very high. Cell 9 had a lower potential near the surface than at the lower depths perhaps due to the influence of the iron sulfide layer which was near the surface. More time may be required to permit the Eh values of Cells 6-9 to stabilize. The fact that Cells 5 and 10 had reasonably good profiles indicates that the probes are functioning properly and that soil differences are not preventing the expected Eh profiles from developing.

Time domain reflectometry revealed that under saturated conditions (FIG.2) the TCPL soil (Cells 5,7,9) possessed a volumetric water content of approximately 45-50% while the NOVA soil (Cells 6,8,10) possessed values of approximately 65-75%. Loss of saturated conditions due to water drainage for leak repair (Cells 5-8, FIG.3) indicate that the water content was reduced by approximately 40% in the shallow depths and was relatively unaffected at the deepest depth of 77.5 centimetres (30.5 inches). These periods of drainage due to leaks and their repair are irregular, but can be considered to roughly simulate the changing water table in the actual environment.

The enumeration of specific bacterial metabolic groups is being undertaken on a repeating basis. Period 1 corresponds to the time between September 12, 1990 and January 31, 1991. Problems with sample collection in Cells 7 and 8 resulted in incomplete data acquisition for Period 1. Period 2 extends from February 1, 1991-May 15, 1991. The enumeration of aerobic heterotrophic bacteria provides a rough approximation of total bacterial numbers which are capable of growing in the presence of oxygen. As the name implies

acid producing bacteria (APB) represent that group of bacteria which can produce various inorganic and organic acids. Their role in corrosion has received increasing attention recently (Pope et al., 1988). Sulfate-reducing bacteria (SRB) produce hydrogen sulfide under anaerobic conditions as sulfate is used as the terminal electron acceptor. The role of SRB in corrosion development has been well documented (Hamilton 1985; Millar 1980). Denitrifying bacteria (DNB) are another physiological group which use nitrate as the terminal electron acceptor instead of oxygen.

During Period 1 aerobic heterotrophic numbers were higher in the TCPL soil in comparison to the NOVA soil (FIG. 4). Numbers were also higher in the cells which did not contain an iron sulfide layer (Cells 5-8). By Period 2 the situation had reversed and it was the NOVA soils which contained the highest numbers (FIG. 12). By the second period it was also evident that in both soil types, numbers were highest at the 12 o'clock position. This suggests that the lower regions of the environmental cells were becoming anaerobic.

With respect to the two soil types, no observable pattern was apparent in the Period 1 enumeration of the acid-producing bacteria (FIG. 5). However, it did appear that with the exception of the 9 o'clock position of Cell 10, APB were higher in cells which did not contain an iron sulfide layer. By Period 2 the highest numbers of APB were noted in the NOVA soils (FIG. 11). In both soil types the highest numbers were generally at the 12 o'clock position, although there were exceptions.

In Period 1 the anaerobic denitrifying and sulfate-reducing

bacteria were more numerous in Cells 9 and 10 which contained the iron sulfide layer, in comparison to the same soil types in cells which did not contain this layer (FIG. 6-7). The acquisition of data for these two groups for Period 2 is still in process.

As an indication of metabolic corrosive activity, hydrogenase assays were performed at the four pipe locations for each cell. This assay will detect the metabolic activity of not only sulfate-reducing bacteria, but also other hydrogen utilizing bacteria which can influence corrosion via a cathodic depolarization mechanism. Hydrogenase activity was detected in all the soil-containing cells but not at all locations in each cell (FIG. 8). A line graph (FIG. 9) reveals repeating patterns in activity. The TCPL soil (Cells 5,7,9) consistently showed activity at the bottom of the pipe (6 o'clock position), while the NOVA soil (Cells 6,8,10) consistently had activity on the top of the pipe (12 o'clock position). Cells 8 and 10 also demonstrated activity at the 9 o'clock position. The 9 o'clock position was the location of the sacrificial anode. Cell 6 which did not have a sacrificial anode did not indicate any activity at this location. Thus, the sacrificial anode appeared to stimulate hydrogenase activity in the NOVA soil. An analogous situation was not observed in the TCPL soil. A consistent correlation between SRB numbers and hydrogenase activity was not apparent (FIG. 10).

CONCLUSION

Water content and redox potential values have been previously correlated with microbial corrosion (Booth et al. 1967). Evidence indicates that sulfate-reducing bacteria and acid-producing bacterial numbers are higher at SCC sites in comparison to control sites (T. Jack, personal communication). A number of trends are evident in our data. The experiment is currently in its seventh month of a 12 month time frame. The previously described parameters will continue to be monitored in order to correlate them with the development of SCC. In addition, steps are being undertaken in order to seed the disbonded areas with bacterial species which may have the potential to induce or enhance SCC.

REFERENCES

Booth, G.H., A.W. Cooper, and A.K. Tiller. 1967. Criteria of soil aggressiveness towards buried metals. III. Verification of predicted behaviour of selected soils. Br. Corros. J. 2:116-118.

Hamilton, W.A. 1985. Sulfate-reducing bacteria and anaerobic corrosion. Ann. Rev. Microbiol. 39:195-217.

Millar,J.D.A. 1980. Principles of microbial corrosion. Br. Corrosion J. 15:92-94.

Pope,D.H., T.P. Zintel, A.R. Kuruvilla, and O.W. Siebert. 1988. Organic acid corrosion of carbon steel: a mechanism of microbially influenced corrosion. p.79/22-79/9 In Corrosion 88, National Association of Corrosion Engineers, Houston.

Table 1. Test matrix.

CELL NO.	1	2	3	4	5	6	7	8	9	10
Loading	One year pressure sequence derived from TCPL line, applied in real time.									
Initial Defects	Two sets of two semi-elliptical slits, 1.5 and 2.3 mm deep in each set. One set under simulated disbonded coating, one on open surface, as shown in Fig. 3.				Eight sets of two semi-elliptical slits (1.5 and 2.3 mm deep) at the 3, 6, 9 and 12 o'clock positions as shown in Fig. 7. At each of these four positions one set will be under simulated disbonded coating and one set will be on open surface. A colony of natural cracks near 3 o'clock position under simulated disbonded coating.					
Crack growth monitoring	DC potential technique for artificial cracks (slits). One probe at the center of each slit.									
					Surface length and distribution of natural cracks measured before and after the test.					
Environment	AGA solution	NS4 solution saturated with CO_2			Soil + Bacteria					
					TCPL Soil	NOVA Soil	TCPL Soil	NOVA Soil	NOVA Soil FeS added	TCPL Soil FeS added
					Variable water table from top of soil to mid-height of the pipe.				Variable water table with FeS in top soil layer as shown in Fig. 7	
Potential (vs SCE)	F.C.	F.C.	-0.8V	-1.1V	F.C.		-1.1V applied through salt bridge at 9 0'clock position (Fig. 7)			

FIGURE 1

Eh PROFILE

FEBRUARY 1991

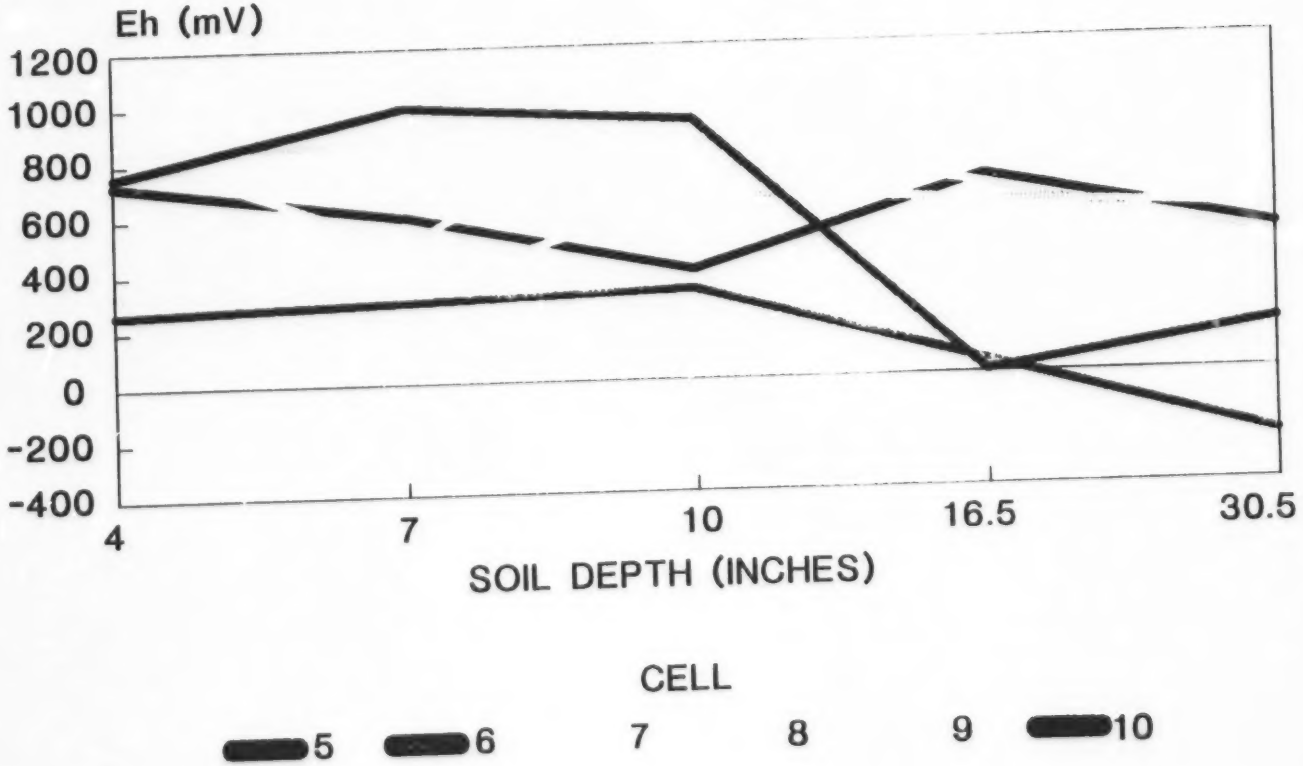
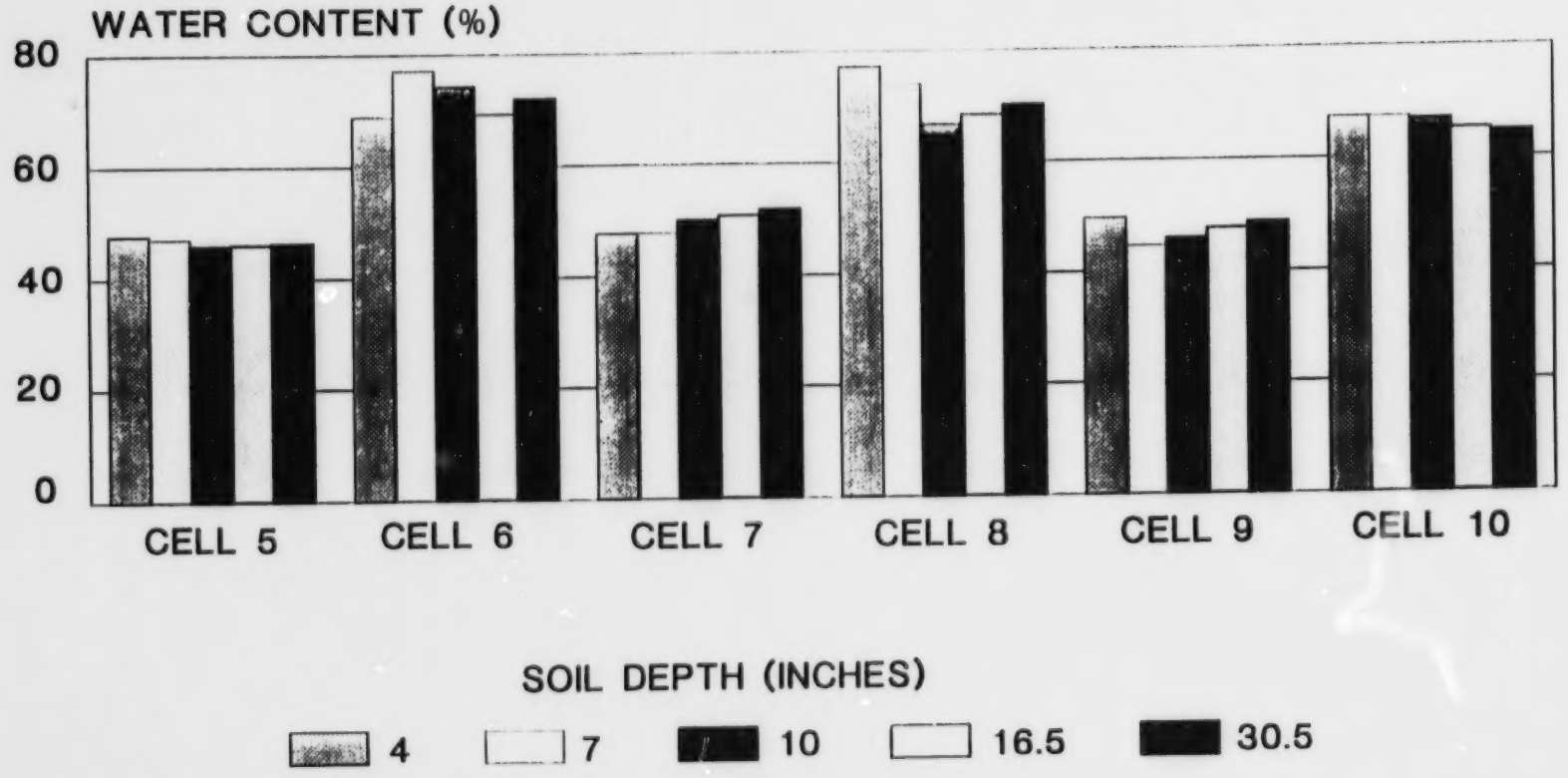
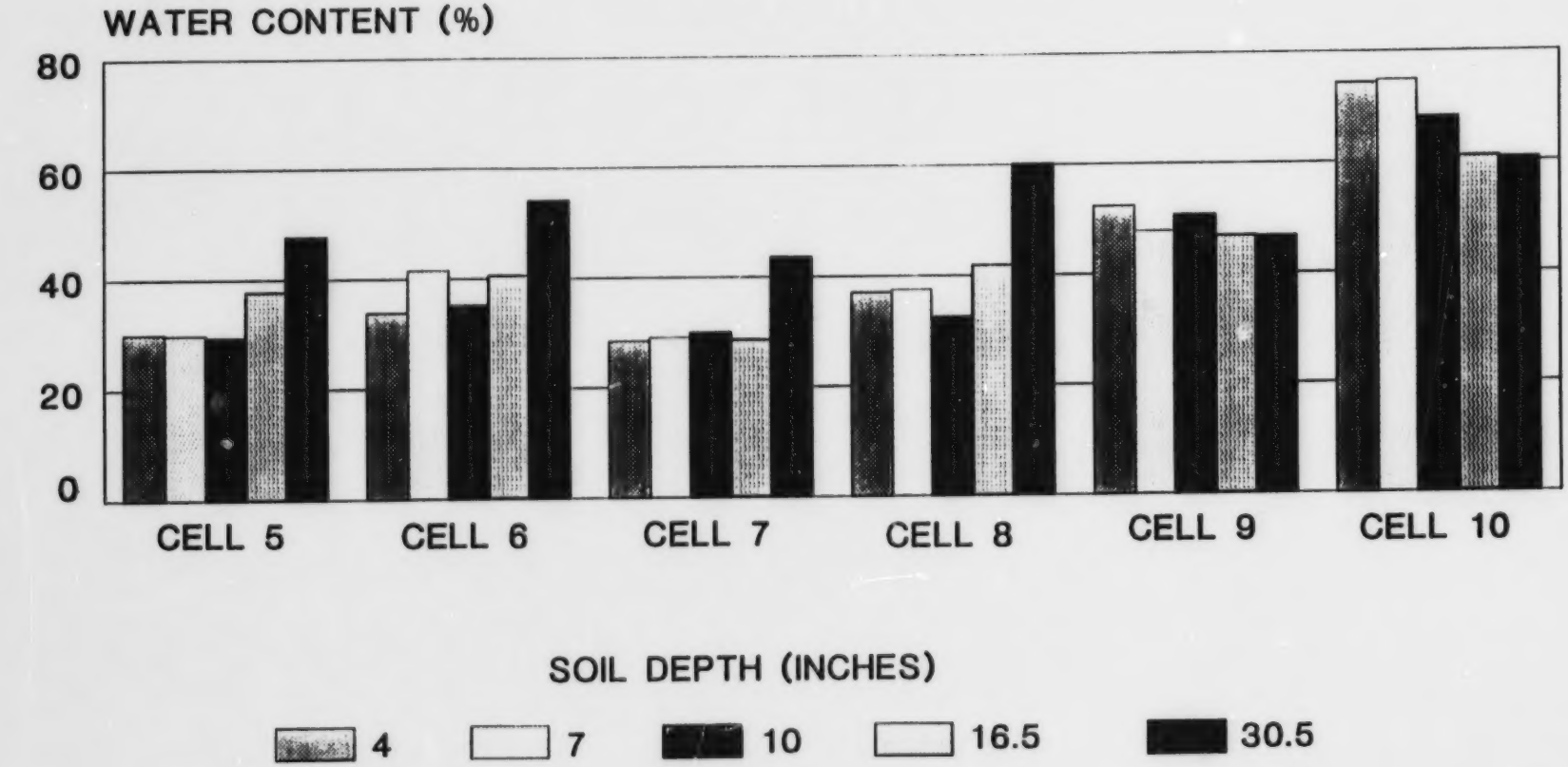


FIGURE 2
WATER CONTENT
FEBRUARY 1991



SATURATED CONDITIONS

FIGURE 3
WATER CONTENT
MARCH 1991



CELLS 5-8 PARTIALLY DRAINED

FIGURE 4
AEROBIC HETEROTROPHIC BACTERIA
PERIOD 1

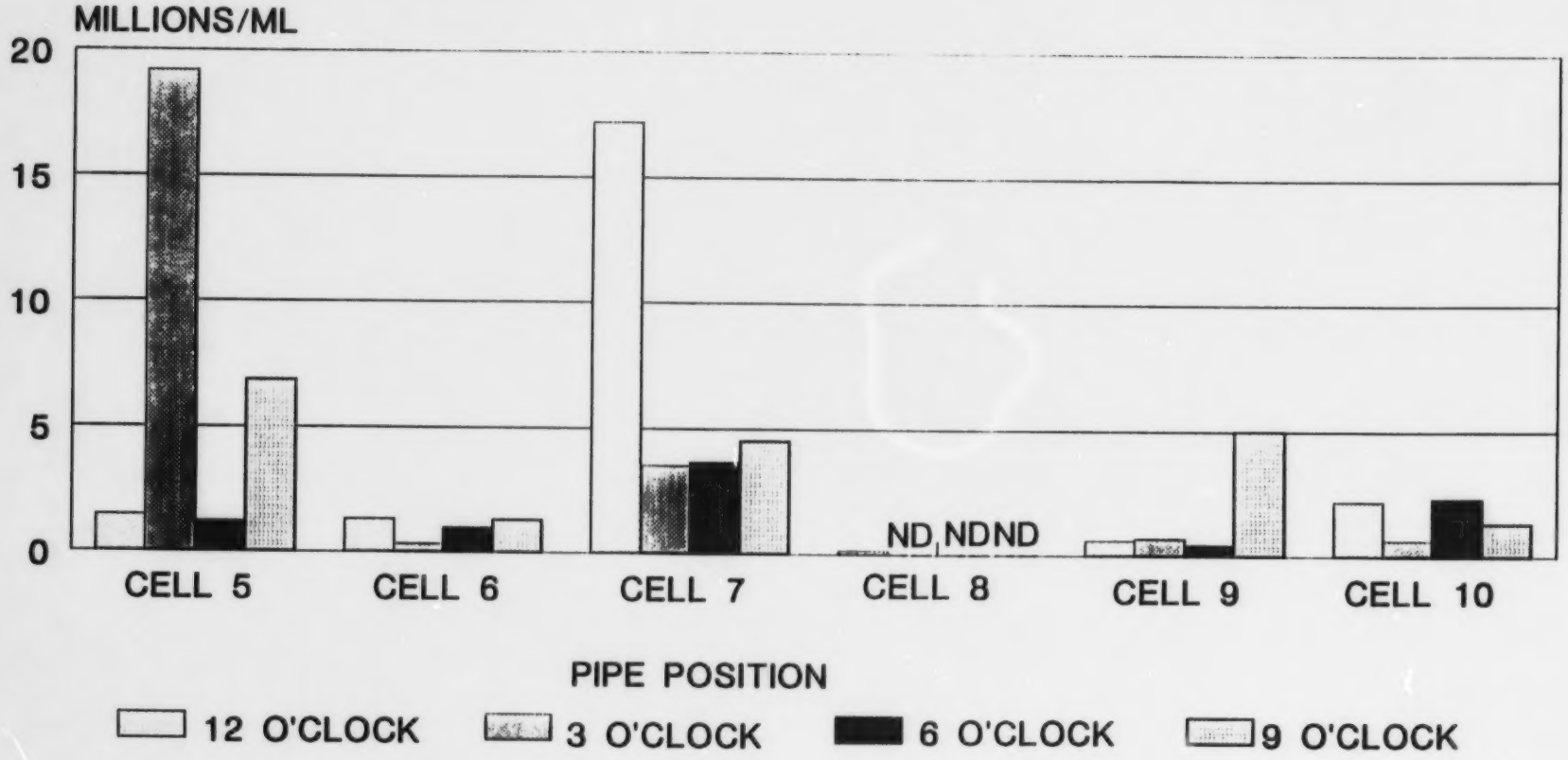


FIGURE 5

ACID PRODUCING BACTERIA

PERIOD 1

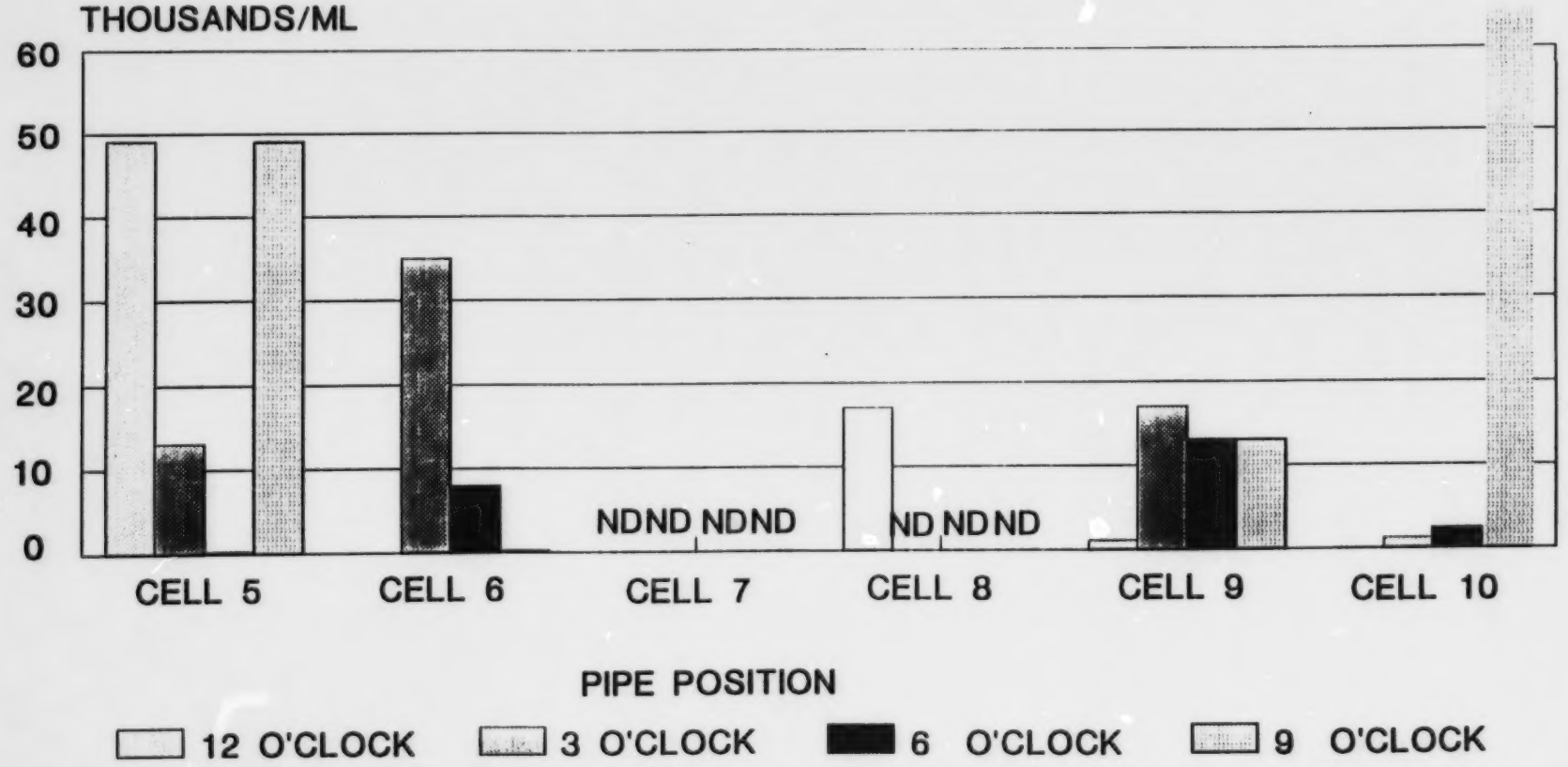


FIGURE 6
DENITRIFYING BACTERIA
PERIOD 1

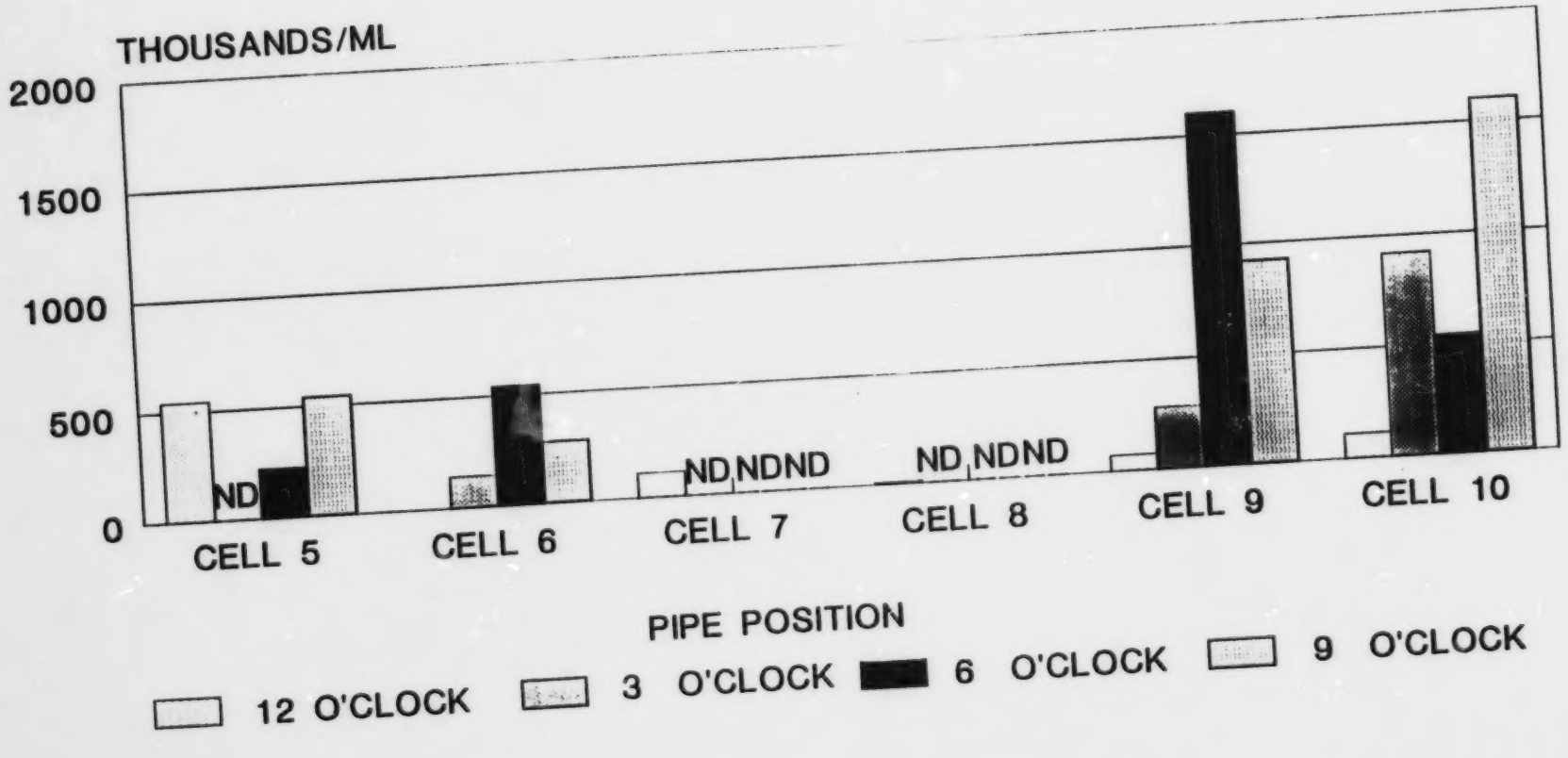


FIGURE 7

SULPHATE-REDUCING BACTERIA

PERIOD 1

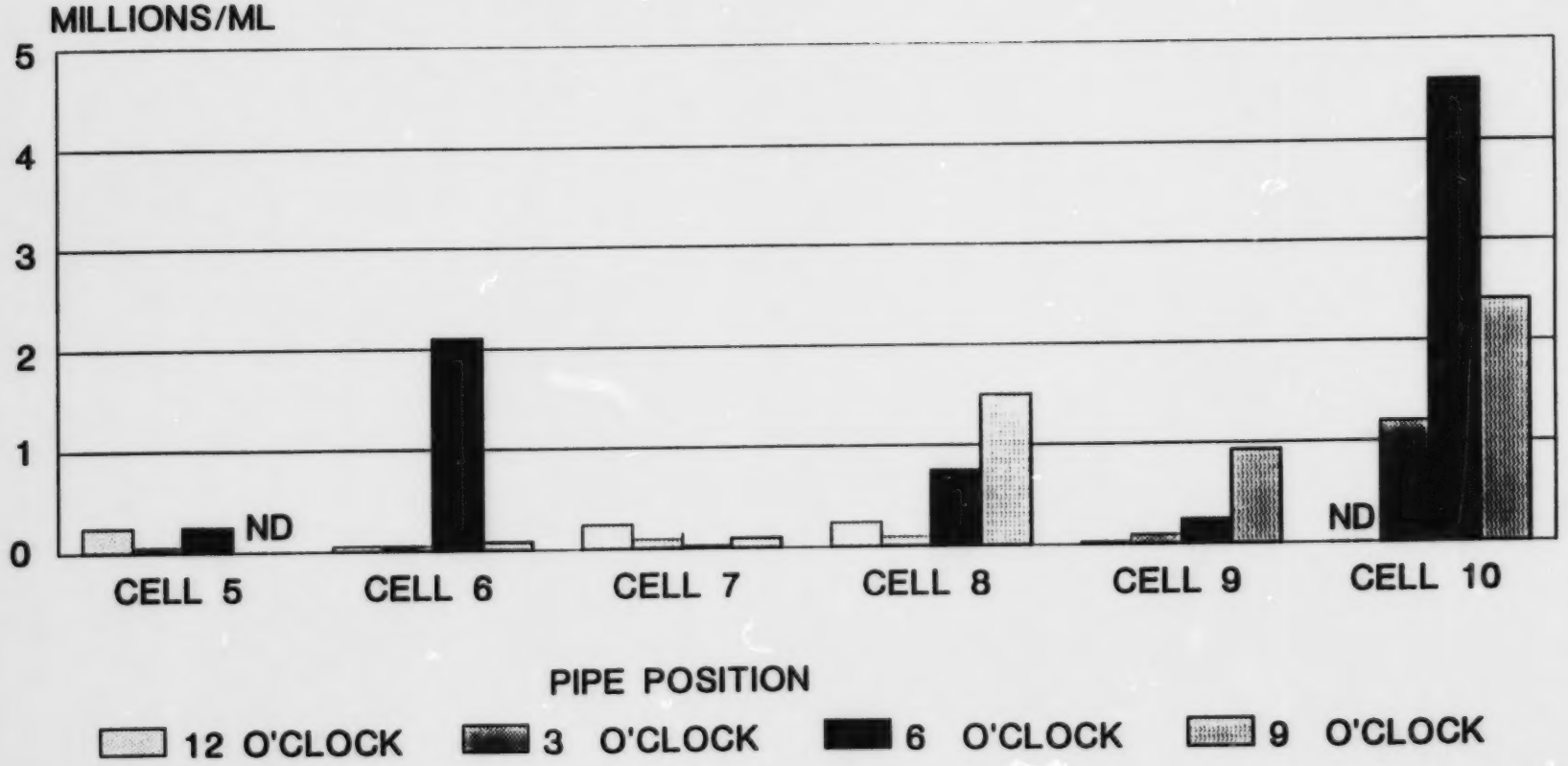


FIGURE 8

HYDROGENASE ACTIVITY

PERIOD 1

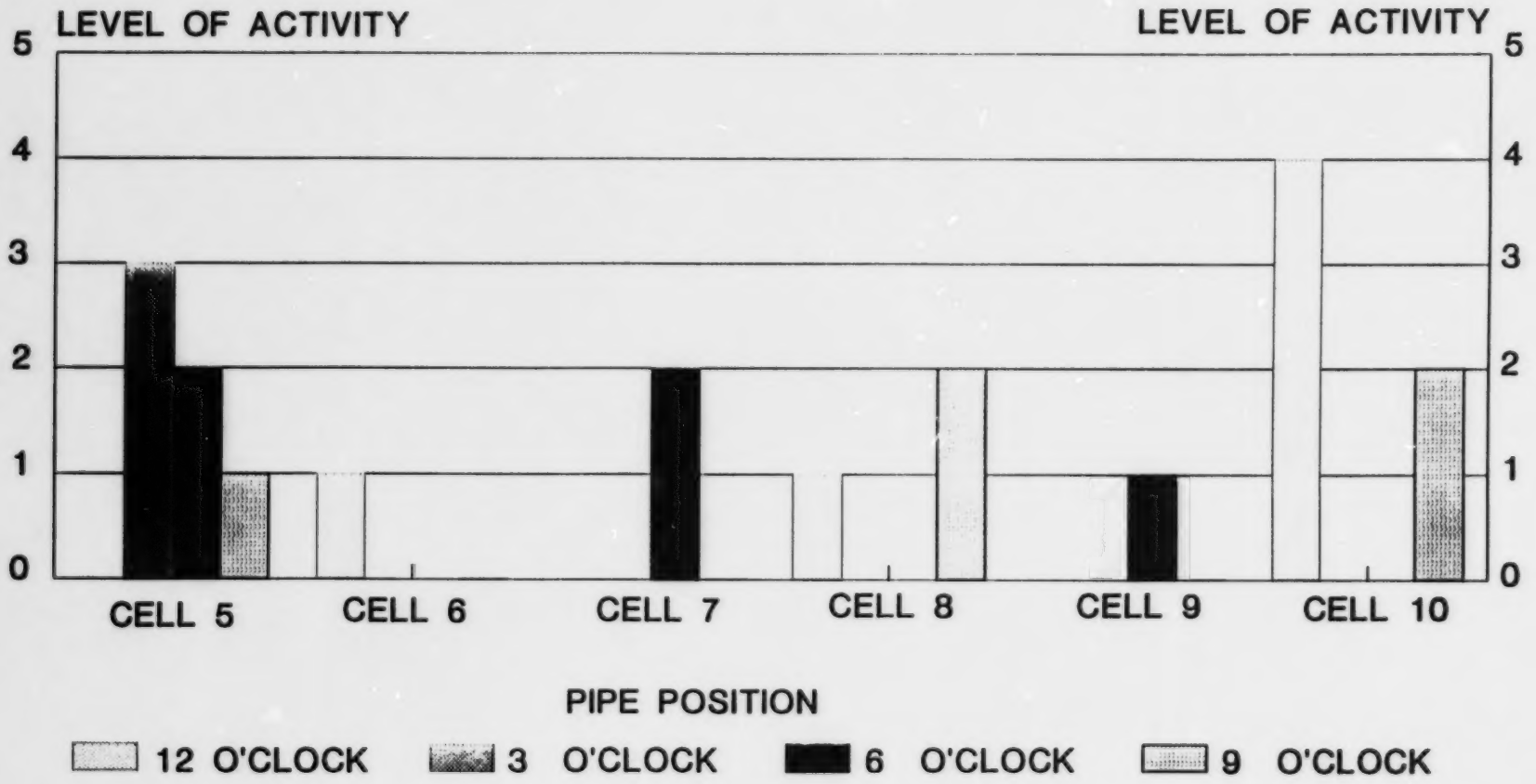


FIGURE 9

HYDROGENASE ACTIVITY

PERIOD 1

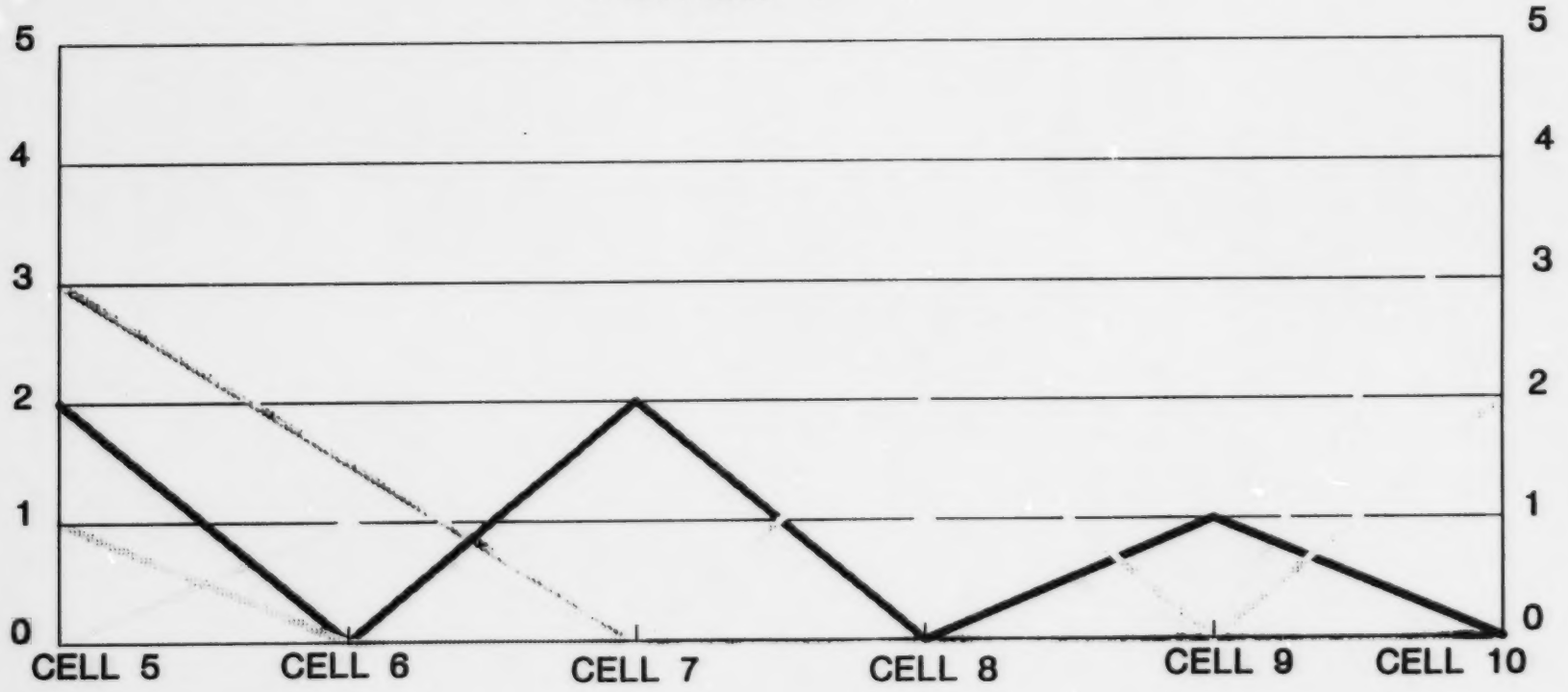


FIGURE 10

SULPHATE-REDUCING BACTERIA AND HYDROGENASE ACTIVITY

PERIOD 1

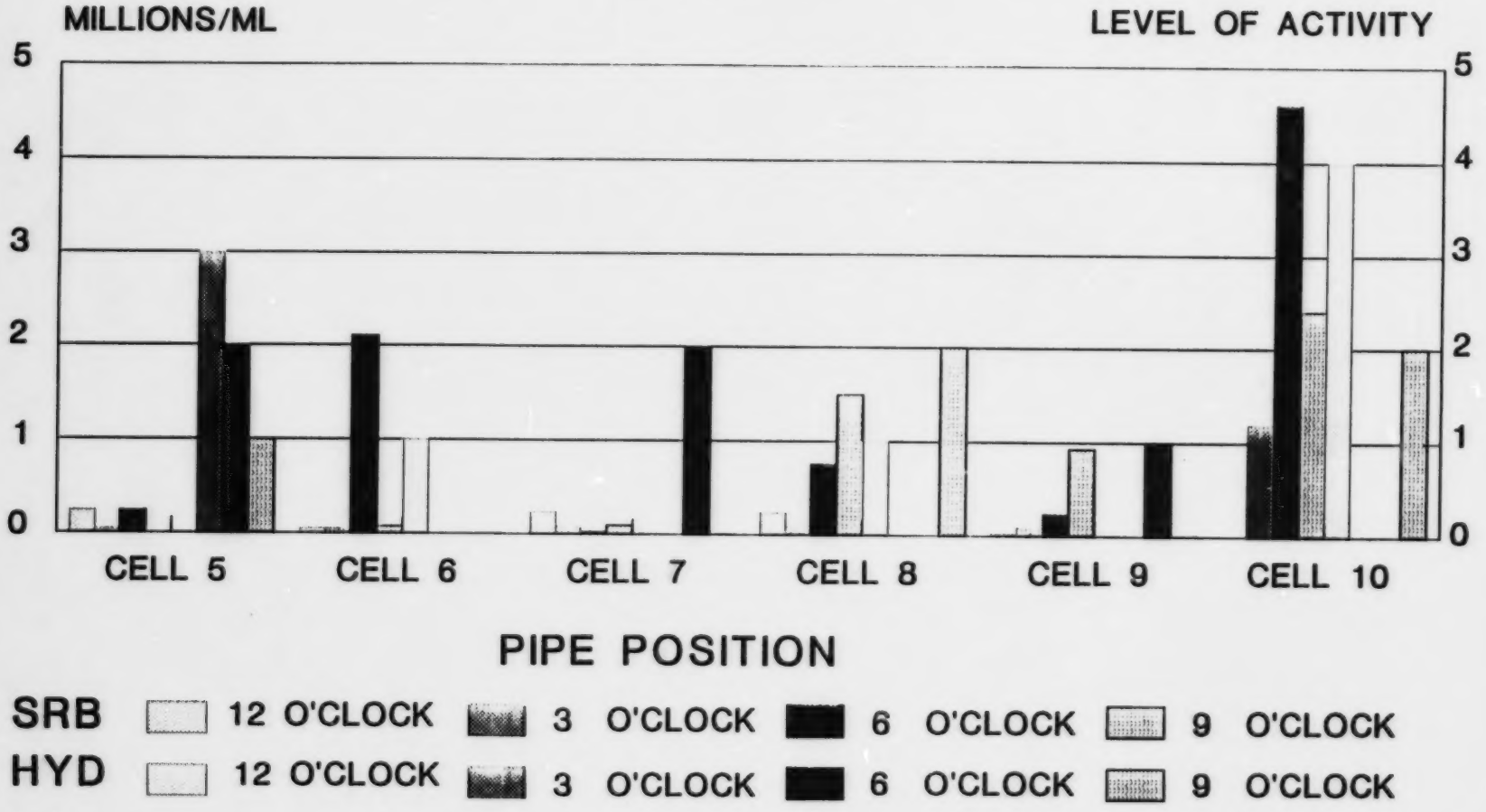


FIGURE 11

ACID PRODUCING BACTERIA
PERIODS 1 AND 2

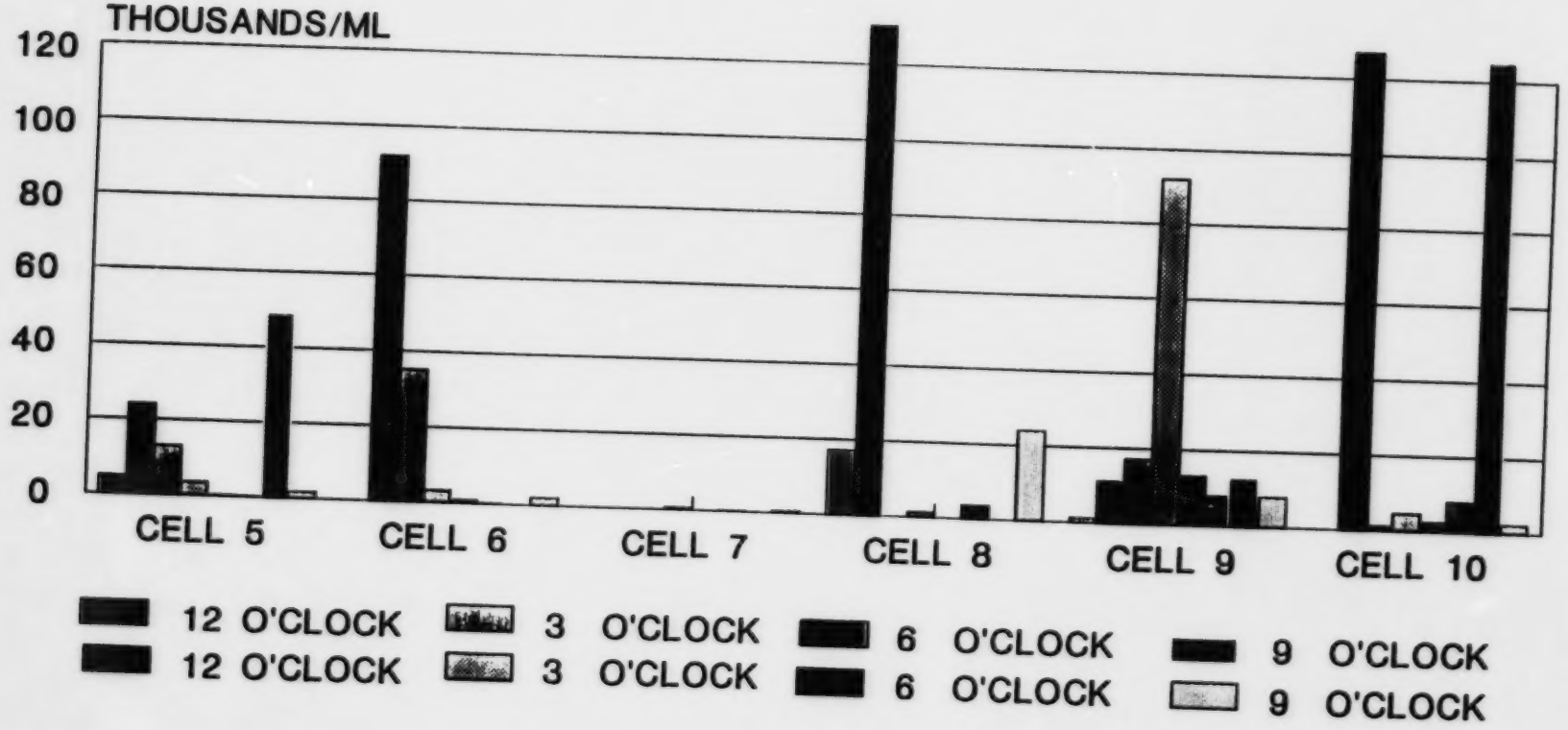
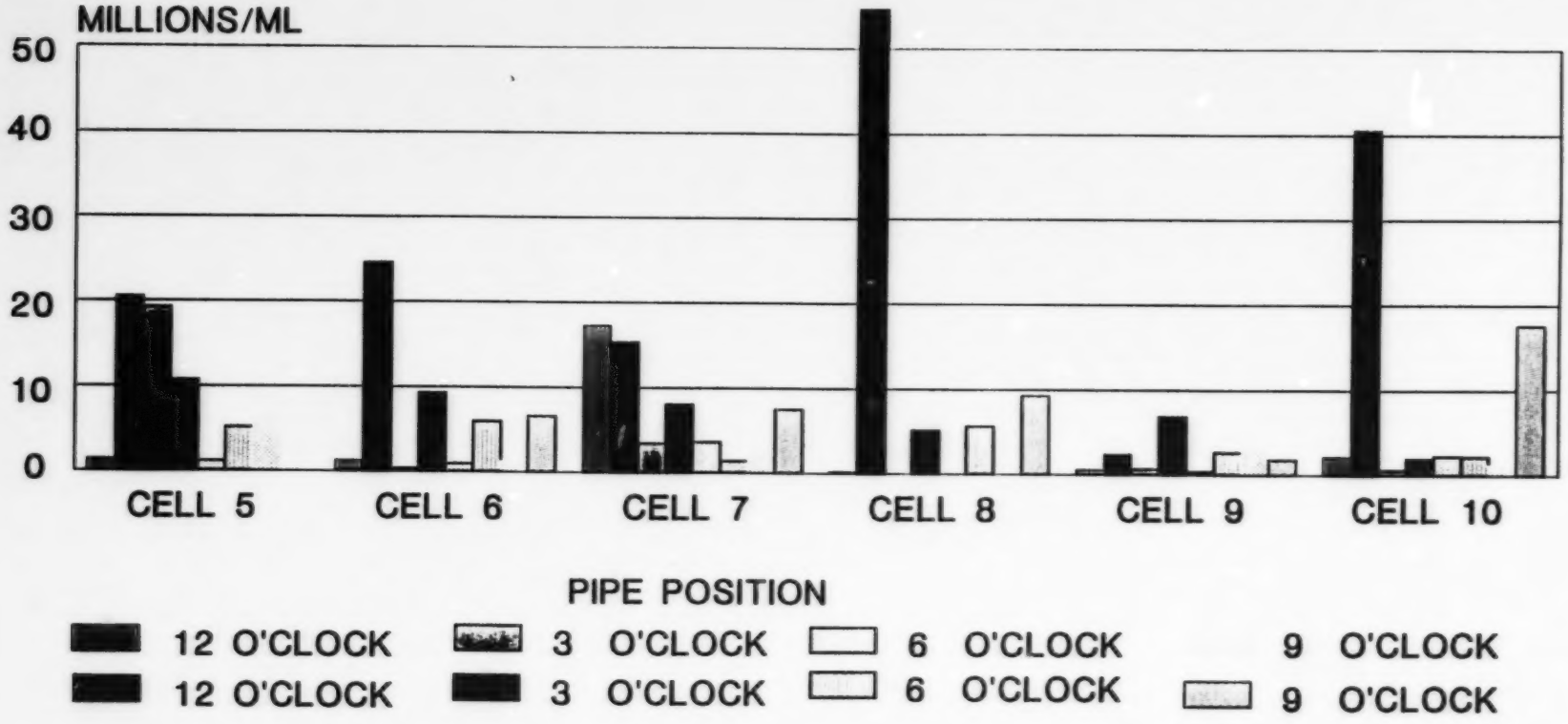


FIGURE 12

AEROBIC HETEROTROPHIC BACTERIA
PERIODS 1 AND 2



APPENDIX 1

Total viable numbers- fifth strength nutrient agar

Nutrient broth	1.6	g
Bacto-agar	20.0	g
ddH_2O	1.0	litre

-dilution blanks : 0.1% sodium pyrophosphate, pH 7.2
-incubate at 28°C for 72 hours.

Acid Producers-MPN

Dextrose	5.0	g (0.5%)
Phenol red broth	16.0	g
ddH_2O	1.0	litre
pH	7.2	

-prepare MPN series with five tubes per dilution, 10 fold dilution
-incubate at 28°C for 24 hours
-reaction : red> yellow

Sulphate-reducing bacteria-MPN

-adaption of Postgate Medium B

KH_2PO_4	0.5	g
NH_4Cl	1.0	g
$CaSO_4$	1.0	g
$MgSO_4.7H_2O$	2.0	g
Sodium lactate	1.75	g
Sodium acetate	1.28	g
Yeast extract	1.0	g
Resazurin (0.1%)	1.0	ml
ddH_2O	1.0	litre
pH	7.2	

-five tubes per dilution MPN, 10 fold dilution
-incubate 30°C for 4 weeks
-detection : blackening of medium

Denitrifying bacteria-MPN

Alexander,M. Denitrifying bacteria, p. 1484-1486. In C.A. Black (ed.), Methods of soil analysis. American Society of Agronomy, Madison, Wis.

Solution A

KNO_3	1.0	g
Asparagine	1.0	g
1% alcoholic soln of bromothymol blue	5.0	ml
ddH_2O	1.0	litre

Solution B

sodium citrate	8.5	g
KH_2PO_4	1.0	g
$MgSO_4.7H_2O$	1.0	g
$CaCl_2.6H_2O$	0.2	g
$FeCl_3.H_2O$	0.05	g
ddH_2O	1.0	litre

-Mix the two solutions, adjust the pH to 7.2, dispence in 9.0 ml volumes and autoclave.
-prepare MPN series with five tubes per dilution.
-add 0.5 ml of sterile 10.0% agar to each dilution tube.
-incubate for 7 days at 30° C , observe daily for a change to a blue color. Observe for gas production.Test for nitrite and nitrate as required (use uninoculated media as control).